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Technical News Bulletin

High-Intensity Electron Accelerator

For New NBS Site

THE National Bureau of Standards will install at its new Gaithersburg (Md.) laboratory facility an accelerator producing one of the world's most intense high-energy electron beams.[1] The electron accelerator is needed to enable the Bureau to keep pace with the new fields of technology that have been opened up by the availability of intense electron beams. Industry has already begun to use such beams to sterilize pharmaceuticals and food, polymerize plastics, and vulcanize rubber.

As part of the Bureau's responsibility for the National standards of physical measurement, it must provide the basic data, standards, and measurement techniques that are needed in this new branch of radiation physics. It has therefore designed an accelerator that could produce electron beams with energies continuously variable from 10 to more than 40 Mev and power outputs greater than 40 kw. This power output is about 100,000 times that now obtained in this energy range at the Bureau. The resultant increase in intensity will make it possible for the Bureau to enter new areas in nuclear and atomic physics, and through such studies to develop standards, measuring techniques, and shielding requirements for the high dose rates now being applied by industry and the armed services.

The proposed accelerator is basically a 100-ft pipe through which electrons are accelerated on the crest of a traveling wave. The waveguide, which consists of nine 8.5-ft sections will be supplied with rf power at an L-band frequency of 1,300 Mc. The first three sections are to be powered by 10-mw-peak amplifiers, the last 6 by 5-mw-peak amplifiers. Either klystrons or amplitrons may be used as power sources, but at present the amplitrons are being strongly considered because they promise greater efficiency, stability, simplicity, and economy. A final decision awaits further life and performance testing of the amplitrons.

Because the acceleration path is a straight line, the device is called a linear electron accelerator, or linac. From the linac, accelerated electrons are ejected in a well-defined, high-intensity beam. The ejected beam can be controlled by magnetic fields and made to interact directly with various materials; or the beam can be directed at certain targets to generate other radiations, such as X-rays, positrons, and neutrons, which can in turn be used for research purposes.

The program the Bureau plans to carry out with the new accelerator is essentially a continuation of present work in nuclear and atomic physics. However, with the increase in electron

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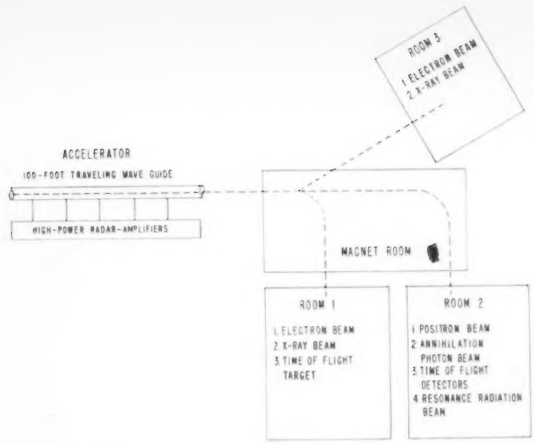

Schematic drawing of the proposed high-energy, high-intensity electron linear accelerator. For most effective utilization of accelerator potentialities, design features have been incorporated which allow the output to be fed into any one of three rooms especially equipped and shielded for specific measurements.

intensity, these activities can be greatly expanded; experiments that previously were impracticable, or which required months of effort and exposure time, can be accomplished with the linac in a matter of hours. For example, it will probably be possible to measure polarization effects in the nuclear photoeffect, thus providing extremely valuable information on the nuclear wave function. Such investigations are almost impossible with conventional electron accelerators.

Complementary to, and depending on, the basic research program is the development of standards and measuring techniques for the strong radiation effects now receiving attention in industry. The proposed accelerator, which provides 10-billion rads/hr, is capable of producing radiation damage in many materials. This dose rate, added to those available from the existing cobalt, radium, X-ray, and electron beam sources at the Bureau, will make it possible to conduct investigations of dosimetry problems in most of the important ranges that are now in use or which can be foreseen.

The usefulness of the proposed accelerator also extends into many other fields. Within the Bureau, it will serve as an experimental tool in research programs such as low-temperature chemistry, solid state physics, metallurgical studies, activation analyses for trace elements, nuclear alinement studies, and property determinations for irradiated materials. On a national scale, still other fields, such as reactor design, will undoubtedly feel the influence of research with the new accelerator.

[1] High-energy, high-intensity electron accelerator, *NBS Tech. News Bul.* **42**, *249 (1958)*.

Conference on Propagation of ELF Electromagnetic Waves

OVER 50 scientists and engineers were invited from industry, Government, and universities to a meeting at the Bureau's Boulder (Colo.) Laboratories on January 26, 1960, to exchange information and ideas on radiowave propagation at extremely low frequencies (ELF).[1] Widespread interest has arisen in this frequency range—less than 3 kc and well below the frequencies now used in radio communication—because of its potential value for communications on a worldwide scale. The observed characteristics of natural ELF fields and the theory of radiation and propagation of waves in the ELF range were discussed at the meeting, which was sponsored by the NBS Central Radio Propagation Laboratory (CRPL).[2]

At extremely low frequencies natural sources, both terrestrial and extraterrestrial, radiate electromagnetic energy. For example, lightning discharges produce considerable energy in this range, and the radiated fields have been used for many years to study lightning phenomena at frequencies as low as 10 cps. In this research, ELF signals have been observed to propagate with very low attenuation. It is known that such signals penetrate with relatively small loss into conducting media like rocks and soil. In fact, frequencies in this range have been used extensively in geophysical exploration.

Because ELF waves have certain magneto-ionic characteristics, they may penetrate the ionosphere and enable communication with space vehicles. This penetration is theoretically feasible in the vicinity of 3 kc, where there is some evidence that a "window" in the ionosphere may exist. Another aspect of these waves is their extremely long wavelength (3,000 km at 100 cps), which would permit signals to be easily diffracted around planetary objects. The conference was scheduled in order that recent ELF data could be exchanged between those working in this field.

First Session

J. R. Wait of the Boulder Laboratories moderated the morning session. An introductory paper was presented by E. T. Pierce of AVCO

Corporation on the nature of the waveforms of signals radiated from lightning discharges. Mr. Pierce demonstrated that the "slow tail" portion of this waveform assists in the calculation of electron densities and collision frequencies for the lower edge of the ionospheric *E*-region.

George Garland of the University of Alberta, Canada, gave a comprehensive paper on the nature of fluctuations in the earth's magnetic field, with particular attention to the magnetotelluric method of investigating the earth's crust. In this method variations in the tangential electric and magnetic fields on the surface of the earth are compared. The changes in the ratio of the frequency spectra of these fields are related to the conductivity of the earth's crust at depths of several kilometers.

The diurnal and seasonal variations of geomagnetic fluctuations were reviewed by W. Campbell of the University of Alaska. He indicated that for frequencies above 2 cps the source of the fields is primarily lightning discharges, and below this frequency, solar effects. In a discussion of geomagnetic fluctuations, P. A. Goldberg of Rand Corp. and E. Maple of the Air Force Cambridge Research Center also held that magnetic energy in the audiofrequency range may be attributed almost solely to lightning discharges.

A. D. Watt and E. L. Maxwell of CRPL discussed the physical phenomena involved in cloud-to-ground lightning discharges as well as the respective roles of the static, induction, and radiation fields. They showed that the radiation field varies directly with frequency below 6 kc. Any observed spectral characteristics which depart from this relation were satisfactorily explained.

A. G. Jean and W. L. Taylor, also of the CRPL staff, described the Laboratory's experimental facilities for measuring the waveforms of atmospherics in the ELF range. With these facilities simultaneous recordings are made of the same atmospheric disturbances at widely separated stations.

E. L. Tepley of the Institute of Geophysics, University of California at Los Angeles, concluded the first session with a statistical report on the characteristics of "atmospheric waveforms." The report contained data on the attenuation rates of ELF signals. For example, rates at 100 cps are of the order of 1 db/1,000 km of path length.

Second Session

In the afternoon session, moderated by A. D. Watt of CRPL, the first paper was presented by J. R. Wait, who had presided at the earlier session. Dr. Wait discussed the effect of earth curvature and the earth's magnetic field in a theoretical treatment of mode theory, with special reference to ELF. He included an analysis of the behavior of the electric and magnetic fields at distances from the source that are comparable to the wavelength.

R. A. Helliwell of Stanford University described certain peculiar qualities of whistler sonograms. These qualities indicate that whistlers sometimes contain appreciable energy at ELF. W. L. Anderson of the University of New Mexico presented a theoretical discussion of the dispersion of electromagnetic pulses propagating in conducting media. He recommended an optimum pulse shape for signalling.

The transmission between two insulated loop antennas immersed in a conducting half-space was evaluated by H. A. Wheeler of Wheeler Laboratories by means of the reciprocity theorem and the known solution of the receiving antenna problem. L. Rawls of the Developmental Engineering Company described the engineering design of buried antennas. The advantages of the system-loss concept were emphasized by K. A. Norton in a presentation of radiation and propagation data by ELF.

A theoretical treatment of the horizontal electric antenna immersed in a conducting half-space was given by R. K. Moore and R. H. Williams of the University of New Mexico. The problem they outlined is a generalization of the Sommerfeld problem concerning a dipole on the surface of the half-space. They considered the impedance of the antenna, using an approximate method that is based on transmission line theory.

A finite cylindrical antenna immersed in a conducting medium of infinite extent was described by C. H. Harrison, Jr., of Sandia Corp. In the case of dissipative media, a modification of the King-Middleton method of iteration for antennas in air is employed. R. S. Macmillan of the University of Southern California told of the university's work in investigating power-line antennas. In these antennas a section of power line acts as a horizontal center-fed dipole. The direction of maximum radiation is vertically upward, and the pattern thus obtained is well suited to ionospheric investigations.

In the final paper of the conference, G. V. Keller and F. Frischknecht of the U.S. Geological Survey reported on electrical investigations of glaciers and ice sheets using audio frequencies. The energy was coupled to the medium by both electrodes and loops. With such techniques it was possible to outline the cross sections of the Athabaska glacier in Alberta, Canada.

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[1] *The following designations were recommended at the conference for extra low frequencies: VLF (very low frequency)—3 to 30 kc; ELF (extremely low frequency)—1.0 to 3,000 cps.*

[2] *Papers given at the conference will appear in early issues of J. Research NBS, Section D (Radio Propagation). An edited transcript of the oral discussions following the papers will also be included.*

Coulometric Titration Gives High Precision

A COULOMETRIC analytical method and a coulometric-titration coulometer—each providing a precision of 1 part in 100,000 for analyzing and evaluating chemical standards—have been developed by the Bureau.[1] These tools for electroanalysis were developed by Dr. J. K. Taylor and S. W. Smith [2] for use in establishing purity of chemical standards and reference materials.

Coulometric analyses are simpler, quicker, and easier to perform than many of the corresponding gravimetric and volumetric determinations. Research in coulometric analysis to date has dealt mainly with the application of this technique to various analyses rather than with the evaluation of its accuracy. The Bureau's present work, however, shows that in accuracy and precision, coulometric methods can equal or surpass the most careful determinations made by classical analytical methods. Titrations reliable to a few thousandths of a percent for both strong and weak acids can be obtained. The method is equally well adaptable to titrating bases.

Coulometric titration is based on the exact relationship between the amount of electricity used in an electrolysis and the amount of chemical reaction produced. Thus, according to Faraday's laws of electrolysis, the number of chemical equivalent weights of a substance produced at an electrode is proportional to the quantity of electricity passed through the solution.

Because Faraday's law is independent of temperature, solvent, and concentration of the electrolyte, the equipment used can be standardized more accurately and conveniently by this method than by indirect analysis with reference solutions standardized by chemical techniques. Results are based on electrical standards and no assumptions are required as to the purity of primary chemical standards. Uncertainties in composition of standard solutions as well as volumetric errors are eliminated. Methods for the control of electrical circuits are well developed so that coulometric titrations are especially suitable for automatic operation.

A direct analogy can be made between classical analytical methods and coulometric analysis. In the conventional volumetric method, the unknown sample is titrated by adding a chemical reagent; in electroanalysis, electrons act as the reagent. Because the electron is essentially a "universal reagent" and because electrical quantities can be measured with high precision, a proposal has been made to the International Union of Pure and Applied Chemistry to accept the electron as a fundamental chemical standard.[3]

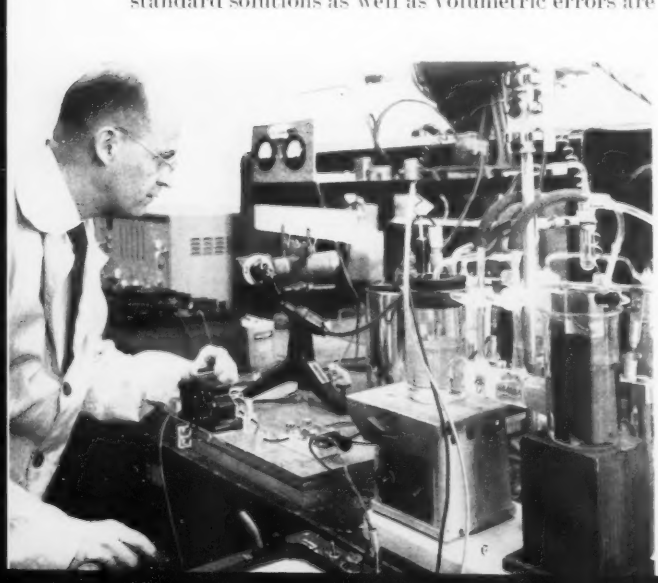
Electroanalysis

Coulometric-titration analysis may be classified either as constant-current or controlled-potential (variable-current) coulometry. In the constant-current method, an accurately measured current is maintained until the desired electrochemical reaction is completed. Then the time required to complete the reaction is multiplied by the value of the current and divided by the faraday constant. This resulting value is a measure of the amount of reactive material present. The electrolysis must be discontinued at the exact end point of the reaction. (End-point determinations may be made by a number of techniques—potentiometric, amperometric, or thermometric—depending on the nature of the particular reaction.)

Controlled-potential, or variable-current, coulometric titrations depend on maintaining the potential of the working electrode at a value that will selectively produce a desired reaction. The electrolysis current accordingly decreases continuously as the reaction proceeds and it is essentially zero at completion. Although no end-point determination is required in this operation, the varying current must be integrated to find the average value before Faraday's law can be used to determine the amount of reactive component. Materials available only in very small quantities may be used in this method because the integrator is capable of measuring small amounts of current.

Constant-Current Coulometry

Bureau scientists have improved the constant-current method by designing a modified titration cell and a procedure for its use. The cell consists of two compartments—one containing a platinum



Coulometric titration coulometer developed by the Bureau. With this apparatus and a coulometric analytical method, a precision of 1 part in 100,000 is achieved in analyzing and evaluating chemical standards and reference materials. Dr. J. K. Taylor sets controls prior to analysis.

cathode and the other a silver anode—separated by fritted glass disks. An alkali chloride solution is used as the electrolyte. For each faraday of electricity passing through the cell, a hydrogen ion is reduced at the cathode and one equivalent of silver chloride is formed at the anode. If a single compartment were used, a small amount of dissolved silver chloride would be deposited on the cathode, causing inaccurate results. The fritted disks and an agar plug at the anode entrance isolate this electrode and also effectively prevent transfer of solution to or from the compartment.

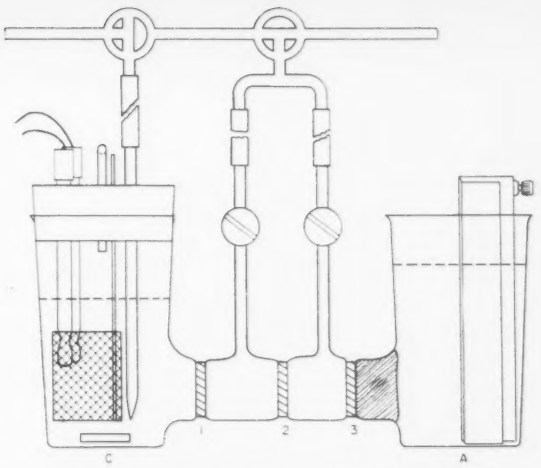
To begin an analysis, the material to be titrated (acidic or basic) is put into the cathode compartment after the specially designed cell has been cleaned. A current of 200 ma is passed through the cell and held constant until more than 99 percent of the acid (or base) has been neutralized. The pH changes are indicated by a pH meter with glass and calomel electrodes. Finally, to reach the end point slowly, a small current is passed through at convenient time intervals. This current corresponds to the addition of a dilute solution in conventional chemical analysis. The pH is recorded after each interval, until the end point of the titration is just passed. By plotting a differential titration curve, the exact end point is located at the maximum of the curve.

Because the accuracy of the results depends on exact measurements of current and time, these quantities must be carefully determined. Accordingly, the current is measured as a voltage-drop across a standard resistor—and compared with saturated standard cells. Both the standard cell and the resistors are calibrated with reference to NBS standards, as is the crystal-controlled time-interval meter.

The reliability of the constant-current method of titration was checked using NBS standard samples certified for composition. Both the precision and accuracy were found to equal or exceed those obtained when using conventional chemical techniques of the most refined type. While the constant-current methods as developed by the Bureau have been largely used for acidimetric titrations, the apparatus and technique are applicable to many other determinations.

Controlled-Potential Coulometry

Because of the selectivity of the controlled-potential method, this technique can be employed under conditions where the constant-current method suffers from interferences, such as simultaneous electrolysis of several constituents. In controlled-potential coulometry, the voltage is maintained at a specific value so that undesired side reactions are eliminated. In this case, however, the current decreases continuously and exponentially during the electrolysis. Thus it must be integrated during the course of the electrolysis. To perform the integration, the Bureau developed the coulometric-titration coulometer. This instrument makes possible much higher precision than the coulometers (i.e., integrators), previously available. Because hydrogen ions are involved, glass electrodes are used to detect the end point. This feature is advantageous because very stable glass electrodes of high refinement that need no further modification are commercially available.



The coulometric titration cell consists of two chambers—one (C) containing the cathode and the other (A) containing the anode—separated by sintered glass disks (1, 2, 3) and an agar plug.

The improved coulometer is essentially an acidimetric titration cell with an electrolyte of hydroquinone dissolved in potassium chloride solution. The current that is being integrated oxidizes hydroquinone to quinone and simultaneously liberates hydrogen ions. When the controlled-potential reaction is complete, as indicated by a low value of the electrolysis current, the polarity of the cell is reversed. The constant-current method is then used to restore the cell to its original composition. The product of the constant current and the time to restore the cell is equivalent to the integral of the current during the original reaction.

Because of the high precision and accuracy of this coulometric integrator, it should provide the basis for controlled-potential coulometric titration with high accuracy. The two methods together should provide a technique applicable to a large variety of analytical situations.

[1] Precise coulometric titration of acids and bases, *by J. K. Taylor, S. W. Smith, J. Research NBS* **63A**, *153 (1959)*. A coulometric-titration coulometer, *by S. W. Smith, J. K. Taylor, J. Research NBS* **63C**, *65 (1959)*.

[2] *Present address, Delco-Remy Division, General Motors Corp., Anderson, Ind.*

[3] Coulometric und das coulombals universelle urtitesubstanz, *P. S. Tutundzic, Anal. Chem. Acta* **18**, *60 (1958)*.

MINIATURIZED THICKNESS GAGES

For Measuring Coatings in Small-Bore Tubes

ACCURATE measurement of coating thickness inside small-diameter tubes is now possible by means of two miniaturized gages [1] designed by the Bureau for the Army. These gages, developed by V. A. Lamb and P. A. Krasley [2] of the electrodeposition laboratory, make use of the reflected field from eddy currents induced in the specimen. They are capable of measuring internal coatings in 0.30-in. and 0.50-in. tubing having lengths of several feet with a resolution of less than 0.1 in. The measurements are, of course, nondestructive and are localized to a small area.

Although the gages were designed primarily for measuring chromium plating in the bores of small gun barrels, they can be adapted for determining the thickness of chromium or other coatings on the interior surface of any small tubing. Other uses may thus be found, as in tubing for various chemical process applications.

As new guns are developed with increasingly higher rates of fire and muzzle velocity, satisfactory performance and firing life require a coating such as chromium plate to protect the steel gun bore from the effects of high temperatures, mechanical wear, and erosion by powder gases. Adequate thickness of the coating, especially in the vicinity of the origin of rifling, is one of the prime requirements in producing high-quality plated barrels.

Up to the present time, the coating thickness had been determined and controlled in the production of gun barrels by measuring the diameter of the bore before and after plating. However, if the plating anode is not concentric with the bore, the plate will be nonuniform. Variations in thickness are not revealed by measurement of the change in bore diameter. Therefore, it became necessary to develop a method for measuring the local thickness of the plate in small gun bores. Available gages were either not readily adaptable for routine inspection or could not be satisfactorily miniaturized for measuring plate thickness in small bores.

Principle of Operation

The Bureau's two thickness gages are based on the "Dermitron," [3] an eddy current type of gage

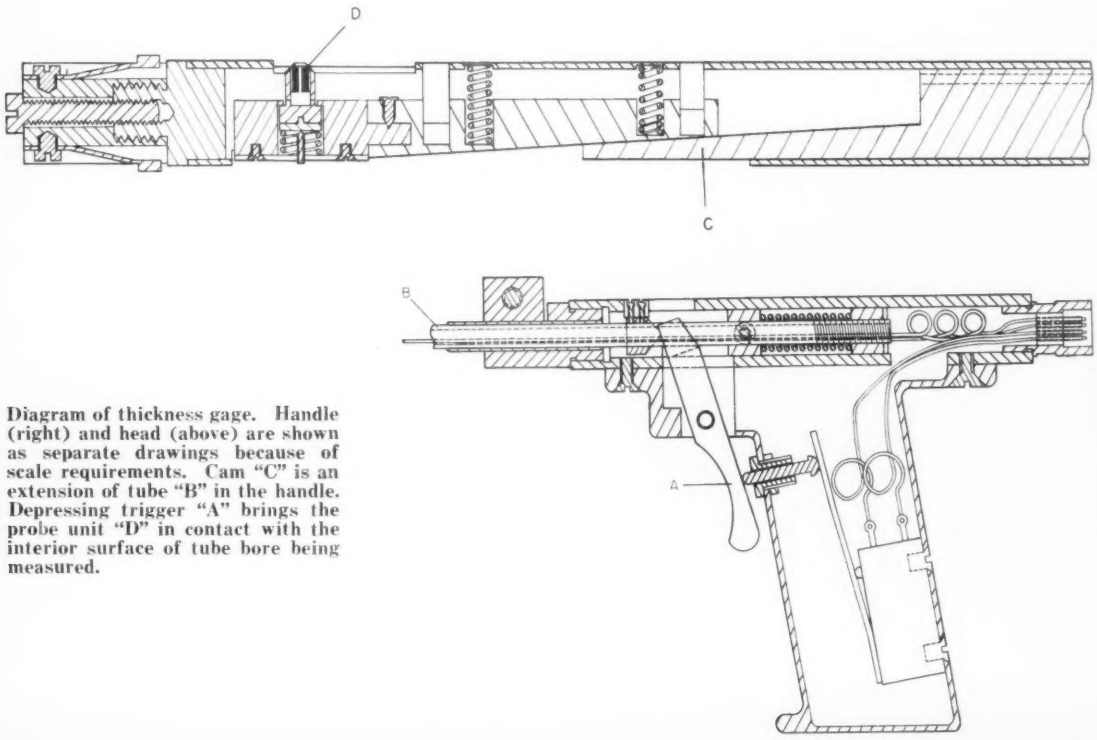


Diagram of thickness gage. Handle (right) and head (above) are shown as separate drawings because of scale requirements. Cam "C" is an extension of tube "B" in the handle. Depressing trigger "A" brings the probe unit "D" in contact with the interior surface of tube bore being measured.

developed in 1954. As in the "Dermitron," a 100-kc oscillator supplies power to a bridge circuit. The probe coil, in parallel with a tuning capacitance, forms one arm of the bridge. The alternating current in this coil, which is placed in contact with the coating, induces an eddy current in the coating. This induced eddy current, which depends on the thickness of the coating, is measured indirectly through the effect of its magnetic field, which opposes that of the inducing current. The opposition of the two fields lowers the impedance of the probe coil.

In practice, it is not necessary to determine the actual impedance of the probe coil. A microammeter indicates the degree of unbalance of the bridge which, with other factors constant, depends on the thickness of the coating. The resulting readings are calibrated in terms of thickness with known thickness samples.

Mechanical Design

These gages differ from the original "Dermitron" basically in size and in the mechanical arrangement used for mounting and controlling the probe coil.

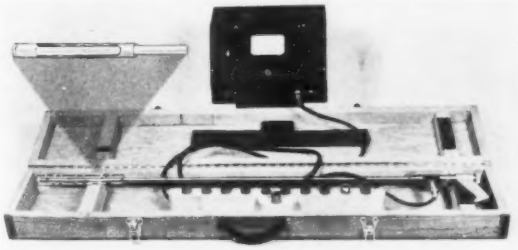
The two gages themselves are similar mechanically. However, the support for the probe coil is necessarily more highly miniaturized in the caliber 0.30-in. than in the caliber 0.50-in. model. Both consist basically of a pistol-grip handle connected to a tubular shaft. In operation, this shaft is inserted into the tube bore to be measured. The probe coil is mounted within the shaft, near the end opposite the handle, with its axis perpendicular to the shaft. A push-rod passes through the shaft to a cam behind the probe coil. Depression of a trigger in the handle moves the tip of the probe coil into contact with the coating being measured. The microammeter which measures the change in current is connected to the probe through an electrical network.

Design of a suitable probe coil having adequate electrical properties was a difficult part of the development. As the lands (raised portions) in the gun barrels are only about 0.06 in. wide, the field from the coil must be limited to a diameter approaching this value. In addition, to fit into the specific available space, the coil is restricted to a maximum diameter of 0.125 in. and to a length of 0.15 to 0.20 in.

Performance

The gages are calibrated by plotting the microammeter readings in the bridge circuit as a function of chromium-coating thickness in standard specimens. These reference samples consist of 3-in. long segments of gun barrel, plated in the bore with known deposits ranging in thickness from 0.001 to 0.008 in. From the plot, the chromium thickness in the barrel bore under test can be read directly. The overall accuracy of thickness determinations with these gages has been found to be ± 10 percent.

The maximum thickness range of the gages was not determined. However, the fact that the calibration curve is nearly linear up to a thickness of about 0.008 in. indicates that considerably higher thicknesses, probably up to 0.015 or 0.02 in., can be measured.



Thickness gage consists of an electronic circuit (center) and a stainless steel tube with the probe unit at one end (left) and the pistol-grip handle at the other end (right). The reference samples used in determining the thickness are in foreground. Inset: magnified cutout view of typical tubing with probe inserted.

[1] *For further information, see* Gages for measuring the thickness of chromium on the internal surface of small-bore tubes, *by V. A. Lamb, and P. A. Krasley, Plating* **47,** *176 (1960).*

[2] *Present address of P. A. Krasley: Electrolytic Section, Bureau of Engraving and Printing, Washington 25, D.C.*

[3] An electronic thickness gage, *by A. Brenner and J. Garcia-Rivera, Plating* **40,** *1238 (1953).* Further studies of an electronic thickness gage; circuitry, operating characteristics and calibration, *by F. P. Brodell, and A. Brenner, Plating* **44,** *1297 (1957).*

1960 Conference on Standards and Electronic Measurements to Meet in Boulder

THE Boulder (Colorado) Laboratories of the National Bureau of Standards will be host to the 1960 Conference on Standards and Electronic Measurements—June 22 to 24.

The conference is sponsored by the National Bureau of Standards, the Institute of Radio Engineers, and the American Institute of Electrical Engineers. Topics to be discussed include recent developments in the precision measurement of electrical quantities (e.g., voltage, power, attenuation, and impedance) from direct current through microwave frequencies, measurements of the electrical properties of materials, and improvements in measuring radio frequency and time.

One half-day will be devoted to an analysis of future problems in the field of electrical standards and electronic measurements.

Transferring Liquefied Gases by Pipeline

LIQUEFIED GASES, such as hydrogen, oxygen, nitrogen, and helium, are widely used as refrigerants in basic research in chemistry, physics, and engineering. More recently these liquids have also come to play an essential part in the propellant systems of rockets, missiles, and satellites. In general, the low-temperature liquids are transported from the liquefier to the experimental setup in insulated, Dewar-type containers.

The current interest in liquefied gases, both in private industry and throughout Government, has led the Bureau to take a second look at accepted methods for long-distance transportation of these fluids. The results of a recent theoretical study indicate that the pipeline method, now employed only in relatively short-distance transfers, can be extended to appreciable distances provided there is an awareness of the performance limitations introduced by undesirable cool-down characteristics. The design of such a system, which in many cases could undoubtedly increase efficiency, safety, and economy, is relatively straightforward. The study, conducted by R. B. Jacobs of the Cryogenic Engineering Laboratory, located at Boulder, Colo., not only provides the theory for designing long-distance pipeline systems for low-temperature operation but also gives information required for numerical computation.[1]

There are two categories of problems encountered in dealing with liquefied gas transfers: those that are predominantly of an unsteady nature and that occur prior to the transfer system's cooled-down condition; and those that can be considered as steady state and are applicable only after the system has been cooled to operating conditions. Only the latter are considered here.

The study has a twofold purpose: first to discover what equipment and techniques are required for the long-distance transfer of the liquids and whether these are available, and second to determine what losses will occur during these long-distance transfers and whether they are tolerable.

The primary component in the transfer's physical system is a length of insulated pipe—the transfer line. The state of the fluid is specified at both the inlet and outlet of this line. Either pumping systems or a process plant, such as a liquefier, can supply the energy required to force the fluid through the line. Pumping stations distributed along this transfer line may be more desirable than supplying all the necessary energy at the inlet. In this case, the system consists of a series of pipes with the fluid state specified at the inlet and outlet of each pipe. Since it is wasteful to carry unavailable energy (as sensible heat) through the system, intermediate stations along the line cool the liquid by one, or both, of two methods: refrigeration or flashing. If the liquid is flashed to atmospheric pressure, its vapor is discarded or piped back to a liquefier and the remaining liquid, which is at its normal boiling point, is pumped through the next section of pipe.

The Bureau's conclusions are derived from a mathematical model based on the laws of conservation of energy, momentum, and mass. These laws were used along with verified assumptions and empirical data to yield a complete, unique model consisting of 12 equations which describe the flow characteristics of a transfer line. This flow model permits the design of a transfer system by relating all the pertinent design parameters: flow rate, line length, line diameter, pumping pressure, heat leak, and fluid properties.

Since the technical design of a system leaves economic and feasibility questions unanswered, the Bureau undertook further studies based upon the loss of liquefied gas in the system. There are four ways in which losses occur: Loss at the pump due to energy dissipation in the pump container and cooling prior to line entry; flashing loss caused by heat leak and energy introduced by the preceding pump; cool-down loss which occurs when the system is cooled from ambient to operating temperature; and trapped-liquid loss from liquid that cannot be removed at the end of the transfer. The Bureau formulated relations from which each loss can be computed and expressed them in a form which facilitates the required computations.

In using the mathematical formulations to design a particular system, empirical information must also be employed correctly. Equations for heat leak and fluid drag have therefore been included.

The Bureau is now in the process of experimentally verifying its theoretical conclusions on long-distance transfer systems. In addition, the operating data on some large systems currently being built will be used in an effort to put the present results on a firmer basis.

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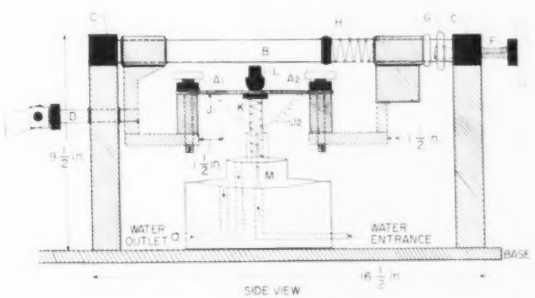
[1] Single-phase transfer of liquefied gases, *NBS Circ. 596 (December 1, 1958). Available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Price 30 cents;* Cryogenic piping systems design considerations, *by R. B. Jacobs, Heating, Piping, and Air Conditioning* **32**, *129 (1960).*

Measuring Water Resistance of Leather

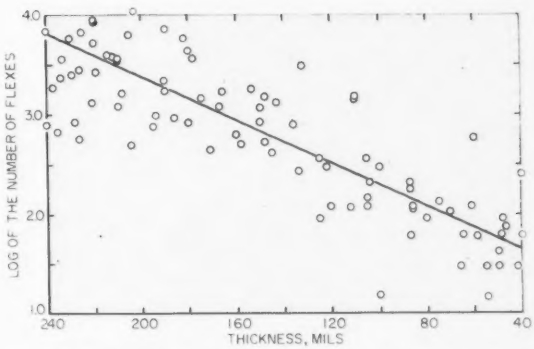
THE Bureau, in its studies of the properties of materials, has been investigating the water penetration of leather, as well as the effects of thickness, location on the leather bend, and compression on water resistance.[1] To obtain significant data on these variables, an apparatus has been designed to flex a specimen with one side exposed to water until penetration occurs. Experimental data obtained with this machine should aid in the development of improved impregnants for waterproofing sole leather.

Because of its flexural properties, durability, and ability to transmit water vapor, leather, is a highly desirable material for footwear. However, its porosity makes it susceptible to liquid water penetration, and to improve it in this respect, leather is treated with various substances. Previous attempts to evaluate the effectiveness of these treatments by static methods have been unsuccessful because sole leather in use is subjected to a flexing action that influences penetration. Hence, a dynamic test method was devised by T. J. Carter to simulate the actual wear conditions that leather undergoes in service.

In this method, a 3- by 6-in. leather specimen, held horizontally between two vertical plungers by movable jaws, is flexed through a 90° angle of bend as the jaws move first toward and then away from each other. As the specimen bends downward, it forces the lower plunger into a water tube to produce a spray on the under side of the specimen. The jaw assemblies, mounted on a rigid base, are operated through couplings by a ratio-motor geared to 30 cycles/min. Steel tracks in the top section of the apparatus support and guide the jaws.



Cross-sectional view of machine designed to measure the water resistance of leather. A_1 and A_2—jaw assemblies; B—support and tracks; C—end panels; D—motor couplings; F and G—set screw and spacer bar; H—compression spring; J_1 and J_2—unflexed and flexed specimen; K—lower plunger; L—upper plunger; M—water container.



Logarithm of the number of flexes required for water penetration, plotted against specimen thickness. Straight line indicates the trend of the data.

As the specimen returns to its original position, the lower plunger rotates to give a gently abrasive effect. The upper plunger, curved to conform to the crease in the bent specimen, rocks back and forth against the upper side of the specimen during the bending cycle. As soon as water contacts the upper plunger, which also serves as an electric terminal, an electronic device connected to the apparatus detects penetration, the end point of the test.

The machine has been used to study both commercial specimens and specimens prepared in the Bureau laboratory. The tests showed that chrome-retanned and vegetable-tanned crust leathers have lower resistance to water penetration than vegetable-tanned finished leather; however, when vegetable-tanned crust is impregnated with certain polymers, the number of flexes required for penetration is increased from 300 to 4,000. The number of flexes required for penetration was found to be related to specimen thickness. Location on the leather bend affects water pentration, with the butt area most resistant. Compression of the impregnated leather before testing decreases the rates of both water penetration and absorption.

[1] *For further technical details, see* Water penetration testing machine for sole leather, *by T. J. Carter JALCA* **55**, *139 (1960).*

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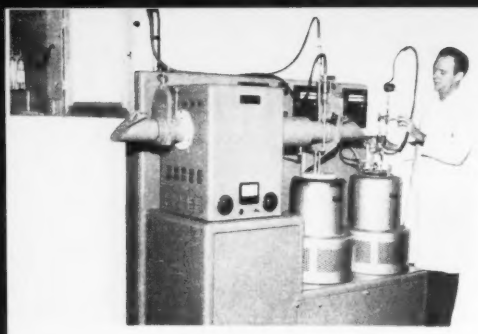
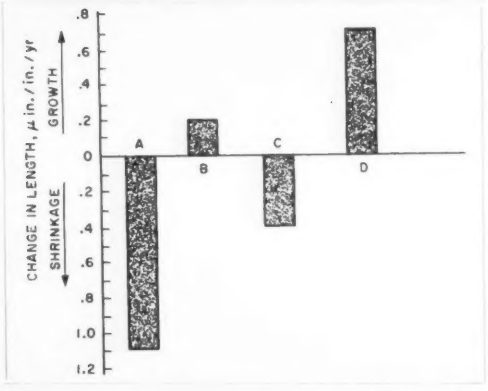


EXTREMELY STA

For Precis asur

Above: **Nitriding 410 stainless steel gage blocks. T. P. Royston hardens gage blocks by exposing them between 40 and 44 hr to a dissociated ammonia atmosphere maintained between 1,010° and 1,030° F.** *Left:* **Neutral salt baths employed to harden 52,100 steel gage blocks. M. R. Meyerson removes the blocks from a chloride bath where they were immersed at 1,550° F for 15 min.**



***Left:* Bar chart comparing the stabilities of: commercial AA grade steel gage blocks (A); NBS-developed nitrided 410 stainless blocks, with nongaging faces left unground after nitriding (B); NBS-developed hardened and stabilized 52100 blocks (C); and NBS-developed annealed 52100 blocks, coated with tungsten carbide (D). The figures are averages of measurements on all blocks of each of these types.**

Grace Chaconas selects a pair of gage blocks from the rotating disk in the foreground and positions them in a mechanical comparator. Such comparisons, carried out in accordance with a specially designed statistical procedure, provide data on the stability of gage blocks. The glass shield in front of the operator and the heavy glove prevent body heat from affecting the operation.

IN A LONG-RANGE research program aimed at an accuracy of 1 part in 10 million in gage block calibrations, the Bureau has recently made significant advances with the development of highly stable blocks and ultraprecise measurement techniques.[1] Three types of gage blocks, produced by M. R. Meyerson of the metallurgy laboratories, show dimensional stability considerably greater than the best commercial blocks. To obtain precise data on the small dimensional changes occurring in the blocks, special measurement techniques were devised by metrologists T. R. Young and W. R. Ney.

Gage blocks, carefully made of steel to exact dimensions, are used to monitor manufacturing processes in the mass production of interchangeable machined parts. As reference standards for such high-precision manufacturing operations as the making of machine tools, ball bearings, and missile control mechanisms, gage blocks must be capable of providing measurements precise to within 1 part in 100,000, and, with the advent of the space age, to 1 part in a million. Therefore, as the length of a block must be known even more accurately than the measurement referred to it, gage blocks certified to 1 or 2 parts in 10 million must soon be available on a regular basis.

To meet these ever-increasing demands for precision, the Bureau is focusing attention on the characteristics of the gage blocks themselves as well as on the equipment and methods for measuring them. Because of the industrial importance of this work, a group of private firms is helping to support the metallurgical research underlying the fabrication of precision gage blocks and the developmental metrology basic to achieving calibrations of the required accuracy.[2]

Gage Block Metallurgy

A special effort is being made to develop gage blocks that will retain their calibrated lengths to high accuracy over a considerable period, with much less shrinkage or growth than is normally expected of precision gage blocks. At the same time, other requirements for gage blocks cannot be neglected. These include an appropriate coefficient of thermal expansion, a high degree of

STLE GAGE BLOCKS

Precisi…easurements

surface finish, flatness of surface, parallelism of opposite gaging faces, and resistance to wear, deformation, and atmospheric and fingerprint corrosion.

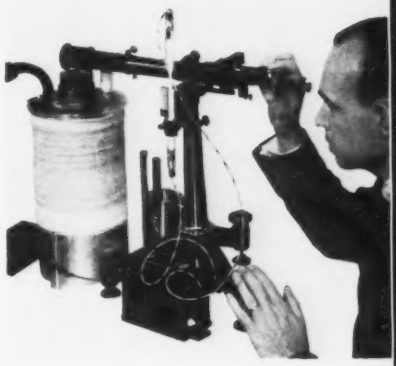
Dimensional instability in steel blocks is thought to result from structural changes in the hardened unstable structure formed during heat treatment and the subsequent redistribution and relaxation of fabrication stresses. Therefore, a properly fabricated block of fully annealed steel of low-alloy content, at or near its equilibrium condition, should be free from subsequent structural changes. However, such a block is too soft to use as a gage block because an adequate surface finish cannot be applied, wear is high, and the surface is easily deformed. An alternate approach is to lower residual stresses in hardened steels by stress relieving in the vicinity of 1,000° F, but this process also makes most hardened steels too soft.

To produce a hard, wear-resisting surface on the annealed material, the Bureau nitrided several steels, chromium plated some, coated others with either tungsten carbide or aluminum oxide, and sprayed still others with nickel-chromium-boron alloy. In attempts to improve the hardened steels, the Bureau tried to eliminate as many of the unstable constituents as possible, and to reduce fabrication stresses. Some blocks were case-hardened on the surface through the processes of carbonitriding, carburizing, and cyanide hardening.

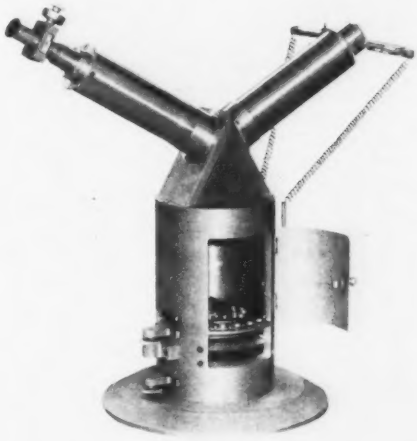
Sufficient data have been obtained on blocks of 410 stainless steel and 52100 modified steel to indicate that such methods can result in greatly improved stability. Annealed 410 stainless steel blocks with nitrided surfaces have been produced which exhibit a growth of only 0.0000002 in./in./yr during the first year of observation, and 52100 steel gage blocks, given special stabilizing and stress relieving treatments, display a shrinkage of 0.0000004 in./in./yr. At present, 16 materials are under investigation and have been given a total of 42 different treatments.

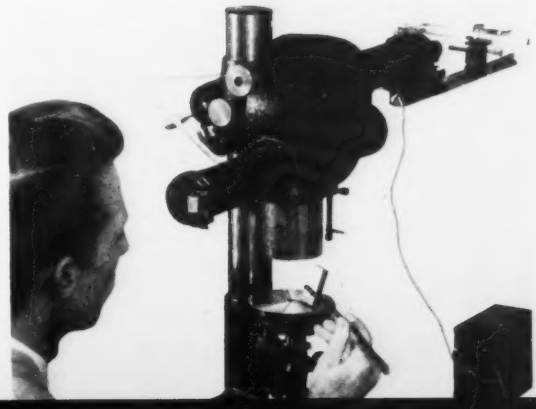
Gage Block Measurements

In evaluating the stability of gage blocks, the Bureau employs two types of measurements: "static" comparisons which are carried out interferometrically and "dynamic" comparisons which



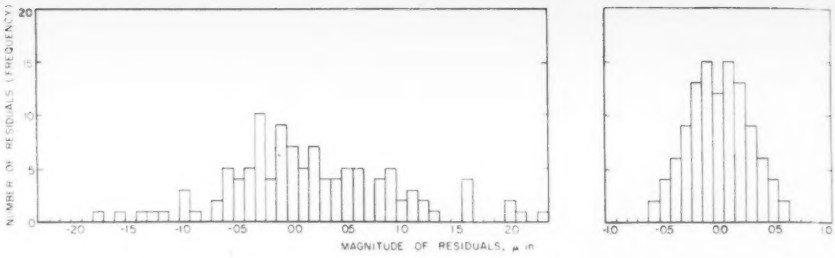
Above: **Group of gage blocks investigated for stability. In front is one of the most promising blocks, made by the Bureau of nitrided 410 stainless steel. Other blocks (left to right) are: a commercially manufactured experimental solid aluminum oxide block; a nitrided 410 stainless steel block with nongaging faces left unground after nitriding; a martempered, stabilized 52100 block with a hardness of 65 R.; and a martempered stablized 52100 block with a hardness of 60 R.. *Right:* R. K. Kirby uses an interferometer to determine the thermal expansion of a gage block.**

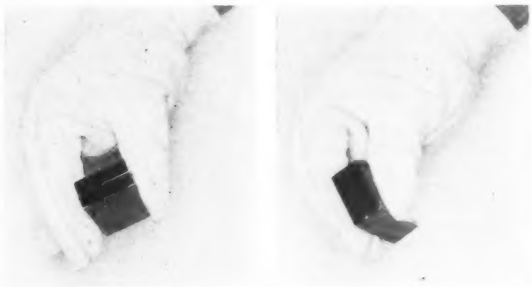




Above: **Interferometer employed in testing the parallelism of gage block surfaces. Two fringe patterns, seen in the instrument's eyepiece, are parallel if the two surfaces of the block positioned inside the housing are parallel. *Right:* J. Nelson positions a 2-in. gage block in an interferometer for flatness testing.**

Right: **In early measurements of gage block stability, a wide spread in residuals, indicating a lack of precision, was obtained (left). With the refinement of the measuring technique, the residual errors were reduced to form a nearly Gaussian distribution, indicating a theoretical precision of ±0.24 μin. for each intercomparison result (right).**





So small a detail as the way in which gage blocks are held has a significant effect on the results of intercomparison tests. In the left illustration an assymetrical thermal effect is caused by one block being nearer the palm than the other. Photograph at right shows how a pair of blocks should be held to meet the requirement of like handling.

rely on a mechanical-electronic technique. By exploiting the features of both comparison procedures, it is possible to detect the occurrence of very small dimensional changes and still conduct the large number of weekly measurements which are necessary.

Until recently very precise length measurements were generally accomplished interferometrically. For such measurements, a Bureau-designed comparator is available which is capable of meeting the most rigorous of present accuracy requirements.[3] In this device a test block is compared with an absolutely measured standard length—a steel gage block of established stability with the same cross-sectional dimensions and nominal length (2 in.) as the test block.

However, because comparisons of this type require that the two blocks be at thermal equilibrium, each test takes at least 4 hr. As more than 50 measurements must be made each week, a more rapid technique that would allow measurements to be made immediately after handling was needed. Such a comparison, usually carried out with a mechanical comparator, is called "dynamic" because both blocks are actually changing in length during the measurement as a result of changing thermal conditions. An accurate dynamic comparison can be made between blocks that respond similarly to thermal conditions if these conditions are the same for both blocks immediately prior to and during the measurement.

The mechanical comparator employed in the dynamic length comparisons utilizes electromechanical transducers to indicate the position of two reed-mounted styluses. Gage blocks are successively positioned between the measuring styluses in comparing their lengths.

Before either of these precision techniques is applied, the gage blocks are screened for flatness of surface and parallelism[4] of gaging faces. Only those that meet certain rigid specifications are eligible for stability testing.

Preliminary measurements of linear thermal expansion are also made. For the dynamic comparisons, test specimens can then be divided by thermal properties into groups so that identically handled blocks will have identical responses. This approach has proved very successful in nullifying the effects of dynamic changes on the overall comparison.

One block in each group is selected as a secondary master, and, after being compared with the primary master interferometrically, is compared with blocks in its own group by the mechanical technique. To meet the requirements of like handling of all test specimens, the secondary master is treated as one of the test specimens. All the possible comparisons—$n(n-1)$ comparisons on $n(n-1)/2$ pairs where n is the number of blocks in a group—form one intercomparison test.

The measurement data are then reduced by least squares to provide a calculated value for each comparison. The residual, or the difference between the calculated and observed values, is used to determine the probable precision of results by plotting the magnitude of each residual against the number of times it occurred. These frequency distributions served as a powerful tool in developing a satisfactory measuring technique, precise to 2×10^{-7} in.

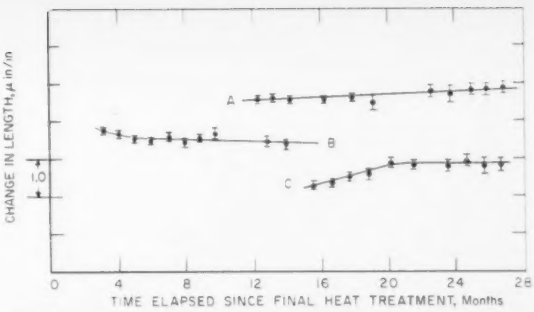
For example, residual frequency distributions have been very effective in prescribing a handling procedure for a two-block test set. Obviously an operator can handle blocks manually with greater ease and assurance than with tongs or other tools

which introduce the danger of dropping. Using insulating gloves, the operator would therefore pick up two blocks simultaneously by their nongaging ends and position them in the comparator in what was considered symmetrical handling. However, it was soon revealed that the manner in which the blocks were held had a significant effect on the symmetry of the residual frequency distributions. It was concluded that handling was producing an unsymmetrical thermal effect—the blocks were held perpendicularly so that one was nearer the operator's palm than the other. After the procedure was changed so that blocks were picked up in tandem with their nongaging ends facing the palm, the statistical distributions showed the expected symmetry.

Promising Results

Of the 16 materials under study at the Bureau, only blocks of 2 materials, 410 stainless steel and 52100 modified steel, have been observed for a year. The most stable blocks were made from the annealed 410 stainless steel, nitrided to a depth of 0.009 in., ground to within 0.003 in. of finished length, stress relieved for 3 hr at 975° F in a cracked ammonia atmosphere, and then finished by lapping the gaging surfaces, leaving a case of about 0.005 in. The nitrided nongaging surfaces when left intact had a frosty gray appearance. Similar stability was indicated by blocks whose frosty layer was removed by further grinding.

The best through-hardened 52100 steel gage blocks were not quite as stable as the two nitrided 410 stainless types, but most of the instability occured during the first 6 months of observation. The 52100 steel blocks were heat treated by austenitizing at 1,500° F for 30 min and quenching in an accelerated quenching oil; and stabilized by refrigerating at −140° F for 18 to 24 hr, tempering at 250° F for 1 hr, refrigerating a second time at −140° F for 18 to 24 hr, and tempering at 250° F for 9 hr. The blocks were ground and then stress relieved at 240°F for 3 hr before a final lapping. This treatment reduces the unstable austenite content to less than 2 percent and produces a block of satisfactory hardness.



Stabilities of a nitrided 410 stainless steel gage block (A); a hardened and stabilized 52100 steel gage block (B); and an annealed, tungsten carbide coated 52100 steel gage block (C), as measured by special metrology techniques.

A fourth block which shows promise, but which has been under study for less than a year, is of 52100 annealed steel coated on the gaging surfaces to a depth of 0.004 in. with tungsten carbide. After surface grinding and lapping, a coating of about 0.0025 in. remained, providing a hard facing. A 3-hr stress relieving treatment in cracked ammonia at 975° F was applied before lapping. An extrapolation of available data indicates that the overall growth of such a block is 0.0000007 in./in./yr, but a substantial improvement in stability during recent months suggests that a much higher stability may be achieved.

Several commercial hardened steel gage blocks of the highest quality (AA grade) were purchased from different manufacturers and observed for stability in the same manner as the Bureau-developed blocks. All of these blocks become shorter, shrinking by an amount ranging from 0.0000007 in./in./yr to 0.0000019 in./in./yr—an average shrinkage of 0.0000011.

A. G. Strang remeasures the length of a standard gage block with an interferometer in terms of the wavelength of light. This measurement serves as a check on the block's dimensional stability. All measurements on gage blocks at the Bureau are related back to a series of these absolute length determinations made since January 1954.

[1] Gage blocks of superior stability: initial developments in materials and measurements, *by M. R. Myerson, T. R. Young, and W. R. Ney, NBS J. Research* **64C** *No. 3, July–September issue.*

[2] *Industrial firms who are actively participating in the program are: Brown & Sharpe Mfg. Co.; Dearborn Gage Co.; DoAll Co.; E. I. du Pont de Nemours & Co., Inc.; Fonda Gage Co.; General Electric Co.; Greenfield Tap & Die Corp.; Hughes Aircraft Co.; International Business Machines Corp.; Link Aviation, Inc.; New Departure Div. of General Motors Corp.; Pratt & Whitney Co., Inc.; The Sheffield Corp.; Taft-Peirce Mfg. Co.; The Timken Roller Bearing Co.; and The Van Keuren Co.*

[3] Gage block comparator, *NBS Tech. News Bul.* **40,** *176 (1956).*

[4] Interferometer for measuring gage-block parallelism, *NBS Tech. News Bul.* **42,** *30 (1958).*

Conference on Foundations of Mechanics and Thermodynamics

IN AN ATTEMPT to correlate the foundations of continuum mechanics with those of statistical mechanics, the Bureau sponsored a Conference on the Foundations of Mechanics and Thermodynamics from October 21 to 23 in Washington, D.C. About 75 scientists participated in the conference, which was designed to explore and appraise various physical principles from both points of view.

At present there are two unrelated approaches to the problems involved in the physics of real materials. One, based upon molecular concepts, is the statistical mechanics of irreversible processes. Scientists in this field attempt to use the general concept of statistical mechanics supplemented by the kinetic theory of transport processes and by phenomenological methods. In recent years they have emphasized the study of the connection between the reversible nature of microscopic mechanics and the irreversibility of processes in real macroscopic bodies.

The other approach is that of rational mechanics. Here theories are concerned with mathematical models of materials defined precisely in terms of properties of invariance. Large deformations, arbitrary states of motion, and nonlinear response are emphasized.

Both fields have advanced greatly in the past few years, but their basic principles have not converged at any point. In general, the methods of rational mechanics have been most successful in describing mechanical and electromagnetic phenomena, while irreversible thermodynamics has been concerned with phenomena related to variations of temperature and entropy. It is believed that integrating the theories and methods in these two approaches would help consolidate the major part of classical physics.

The formal part of the program consisted of five half-day sessions on: The Mechanics of Continuous Media; The Statistical Mechanical Theory of Irreversible Processes; The Thermodynamics of Deformable Media; The Phenomenological Approach to Irreversible Thermodynamics; and World Invariant Electrodynamics. One prepared speaker was scheduled for each session but most of the time was devoted to informal remarks and discussions from the floor. Clifford Truesdell, a Bureau consultant from Indiana University, served as moderator.

Continuum Mechanics

After C. M. Herzfeld, Chief of the Bureau's Heat Division, welcomed the group, Walter Noll, Carnegie Institute of Technology, opened the first session by formulating continuum mechanics in a mathematically rigorous way. The value of this approach is that it emphasizes the assumptions of the theories and their relationships to the conclusions. The method was first illustrated by deriving Cauchy's laws of equilibrium in continuum mechanics. It was then applied to a study of the form of the constitutive equations of a material—such as the caloric equation of state or the stress-strain laws. This introduced the so-called principle of material objectivity, which states that material properties of a body are independent of its orientation in space. Finally ideal materials were classified in terms of associated isotropy groups. An isotropic material is characterized by constitutive equations unchanged by rotation; a simple fluid, by constitutive equations unchanged by the complete unimodular group of transformations.

The relationship between statistical-mechanical theory and rational continuum theory of matter was stressed by John Ross, Brown University. Statistical mechanics may be used to derive or discover the phenomenological equations which define a particular rational theory, to develop the phenomenological coefficients from molecular data, and finally to determine the limits of validity of either the phenomenological coefficients or of the molecular expression for the phenomenological coefficients. For example, it was pointed out that the phenomenological constants "a" and "b" in Van der Waal's equation of state, $(p+a/v^2)(v-b)=RT$, have a particular meaning only in terms of molecular statistical mechanics. A statistical-mechanical derivation of the Boltzmann equation served as a nonequilibrium example.

Thermostatics

Gibbs' concept of stable equilibrium in an isolated system was mathematically defined by Bernard D. Coleman, Mellon Institute, as he explored thermostatics. If a fluid body obeys a caloric equation of state, an internal energy density can be defined for each element of the fluid in terms of the specific volume and entropy. A state of the body is defined as a particular assignment of configuration of the elements and an entropy density for each element. Global stability of a state occurs when every other state with the same total volume and energy has a greater total entropy. Thus for a state to have global stability it is necessary that derivatives of internal-energy density, with respect to entropy density and specific volume, be constant. Finally, a condition

sufficient for the uniform state to be globally stable is that a certain convex inequality in the internal-energy density be obtained. This approach was generalized to include nonfluid bodies for which the internal energy density is an isotropic function of deformation gradients. Local stability of a state was then defined in terms of minimizing a quantity similar to the Helmholtz free energy. Thermal equilibrium seems to associate in a natural way with this concept of local stability.

The equilibrium autocorrelation function is important for the computation of transport coefficients of irreversible phenomena. Elliott W. Montroll, University of Maryland, discussed the fact that the autocorrelation of a molecule's momentum in a perfectly harmonic crystal—shown to be an almost-periodic function for a finite crystal—becomes aperiodic in the limit of infinite number of particles. It was suggested that in this transition from a repetitive to an aperiodic function is rooted the irreversibility of reversible dynamic systems.

Electrodynamics

Combining continuum mechanics with the electromagnetic theory, Richard A. Toupin, Naval Research Laboratory, spoke on electrodynamics. Because the concept of "observer" associated with the electromagnetic theory is different from that of classical mechanics, a generalization of the principle of material objectivity is required. The conservation laws of physics can be expressed independently of the geometric structure of the space-time manifold assumed and thus, independently of the concept of observer. In this theory, applicable to polarizable and magnetizable media, the postulates and equations are separated into two classes: conservation laws independent of the geometry of space-time and constitutive relations depending on or employing a specific geometric structure. The conservation laws assume only an affine space time, i.e., an operator called a shifter is assumed to exist, permitting a comparison for parallelism of vectors separated in space-time.

Constitutive relations involve assumptions on the particular geometric structure of space-time. In this theory, the complications of relativistic continuum mechanics were avoided by using the classical concept of absolute time and allowing the equations to be influenced by an "aether wind." A general equation of entropy production, consistent with the principles of mechanics and electromagnetism, resulted. Innumerable special theories can be based on this equation along with constitutive equations for the various dependent fields, such as heat flux, magnetic flux density and stress in terms of the independent fields of the theory. A special case mentioned as an example was a rational and unified theory containing piezoelectricity, photoelectricity, and the faraday effect.

Design of Corner Reflector Antennas

A DESIGN analysis of corner-reflector antennas has been carried out by the Bureau's Boulder (Colo.) Laboratories under the sponsorship of the U.S. Air Force. The results of this evaluation [1] by H. V. Cottony and A. C. Wilson of the Central Radio Propagation Laboratory provide comprehensive and detailed information on designing high-peformance, economical corner reflectors.

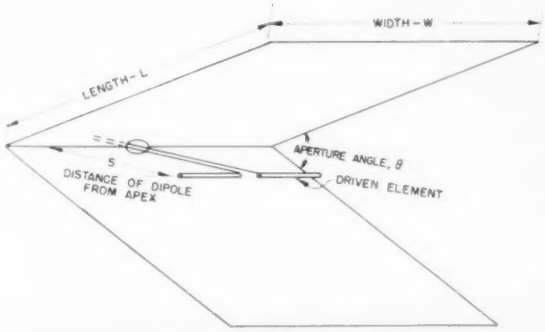


Diagram of corner-reflector antenna.

A corner-reflector antenna consists simply of two plane reflecting surfaces joined edge to edge to form a corner, which is usually parallel to the ground. The driven element is placed in the aperture between the two planes. This type of antenna has the advantages of high gain, broad frequency response, narrow beam width, low back radiation, low cost, and ease of construction.

Early experimental work in ionospheric scatter propagation stimulated interest in corner reflectors because they are particularly suitable for this mode of communication. Even though these antennas had been used prior to the new experimental scatter circuits, their performance was known only qualitatively. Therefore as part of its propagation research program, the Bureau undertook an investigation of corner deflectors to determine how gain varies with changes in width and length of reflecting surfaces, angle of aperture, and position of driven element.

Experimental corner-reflector antenna analyzed by the Bureau. Length and width of reflecting surfaces, position of dipole, and aperture can all be varied to determine effect on gain. This assembly is located at the Table Mesa field station, near the Boulder (Colo.) Laboratories.

Experimental Equipment

The experimental corner-reflector antenna used for this investigation consisted of 2 lattice-type wooden frames, each 12.3 ft (5 wavelengths at 400 Mc) wide by 12.3 ft long, supporting the reflecting surfaces. The reflectors were of overlapping strips of sheet aluminum fastened to the frames so that removal of one strip would subtract 0.2 wavelength from the surface. Width could be varied by trimming the lengths of the strips. The two frames were pivoted along the same axis, and the angle of aperture could be varied form 20° to 180°.

The driven element was a folded half-wave dipole. Its position could be varied from 0.07 to 2.5 wavelengths from the apex of the reflecting surfaces. The dipole's support also served as a balun to transform the impedance of the system to about 50 ohm. Fine adjustment, for an exact match to a 50-ohm line, was provided by a two-stub tuning unit. Gain was measured at 400 Mc by comparing the system with a known antenna.[2]

Although in practice collinear arrays of four and more dipoles are used in scatter antennas to obtain gains of over 20 db, the general performance can be predicted from an experimental system using only a single dipole. Therefore, only the single dipole was used for the measurements.

Gain Measurements

Results of the measurements indicate that minimum reflector width is 0.5 wavelength for the smallest usable value of gain. With an increase in width up to 2 wavelengths, gain increases. However, beyond this, there is little or no increase in gain, and under some circumstances it may actually decrease.

For maximum gain, the dipole must be in one of several discreet positions—referred to as first, second, third, etc., in order of distance from the apex. The exact location of each position is a function of the aperture angle.

When the dipole is in the first position, gain increases monotonically as reflecting surface length increases. When the dipole is in the second or third positions, the same relation holds true generally, except for surface lengths less than 1.5 wavelengths. For these shorter lengths, the relation is not only too irregular for simple analysis but also does not provide the antenna designer with any useful data.

Maximum gain along the forward axis seems to be achieved with the dipole in the second position. In this case, the reflecting surface should be more than two wavelengths long and approximately two wavelengths wide.

Radiation Pattern

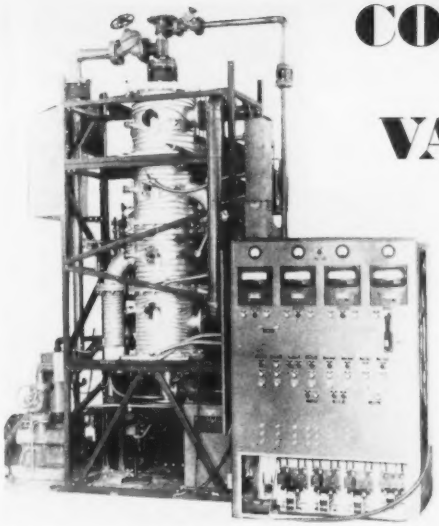
Ionospheric scatter antennas designed for the lowest portion of the VHF band should have especially low secondary lobes and minimal radiation to the rear, as radiation in these undesired directions is likely to result in self-interference from multipath propagation. An important advantage of the corner reflector over other types of antennas is that it can be designed to have extremely low back radiation. The small amount that does occur results from diffraction around the edges and from penetration through small openings in the reflector surfaces.

Radiation patterns have been compiled for a variety of sizes of corner reflectors.[1] This material has been further summarized graphically so that beam widths and back radiation levels for any combination of surface lengths and widths are easily determined.

[1] *For further technical information, see* Gains of finite-size corner-reflector antennas, *by H. V. Cottony and A. C. Wilson, IRE Trans. Ant. & Prop.* **AP–6,** *No. 4, October 1958.* Radiation pattern of finite-size corner-reflector antennas, *by A. C. Wilson and H. V. Cottony, IRE Trans. Ant. & Prop.* **AP–8,** *No. 2, March 1960.*

[2] Techniques for accurate measurement of antenna gain, *by H. V. Cottony, NBS Circ. No. 598. Available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Price 15 cents.*

CONTINUOUS-PRODUCTION VACUUM FURNACE



Continuous-production vacuum furnace designed by the Bureau. Vertical tube in center is the furnace itself; items to be heated are inserted in top of furnace and withdrawn at the bottom. Surrounding the furnace is the control and vacuum equipment. (Photo courtesy Kinney Mfg. Co.)

A CONTINUOUS-production vacuum furnace[1] for evacuating and sealing ceramic wafer electron tubes[2] has been designed by the National Bureau of Standards for the Navy Bureau of Aeronautics as part of the Navy's industrial preparedness program. Mechanical development and construction of the furnace were undertaken on contract by Sanders Associates, Inc., Nashua, N.H.

With this system, the tube assembly is introduced into a vacuum and heated to a high temperature. The combination of heat and vacuum degasses the tube, and the high-temperature brazes together the metallized surfaces of the ceramic wafers to make a hermetically sealed unit.

The machine was conceived and designed by C. P. Marsden of the electron devices laboratory in connection with a study of industrial processes suitable for fabricating electronic components.[3] The automatic production methods for ceramic wafer tubes required processing the assemblies into completely sealed and ready-to-use units by evacuating, degassing, and sealing in a single continuous operation. The vacuum furnace performs these operations with control of only temperature, degree of vacuum, and time of processing. The high temperature eliminates the need for getters, thus simplifying tube design. The furnace has been used to produce up to 200 tube assemblies an hour.

Essentially, the vacuum furnace is a vertical tube, about 11 ft long, of heat-resisting alloy, surrounded by a heating unit, and open to the atmosphere at both ends. Through this tube passes a series of hollow cylindrical specimen carriers, each separated by a short piston fitting closely inside the tube. These parts are introduced into the top of the tube at atmospheric pressure; once inside, they are evacuated through ports along the side of the tube and through holes in the carriers. The pistons and carriers pass through the tube under gravity feed. In the prototype model, the sliding fit of the pistons maintains the vacuum at 10^{-5} mm Hg, and the central portion of the tube can be heated to 1,000° C. After processing, the parts are removed from the lower end of the tube at atmospheric pressure and at reduced temperature.

With the carrier loading and unloading equipment the machine requires about 15 ft vertically. A 15-ft square of floor area is adequate for the vacuum pumps, controls, and other associated equipment.

The central 7-ft portion of the tube is surrounded by the electric heating element. This element is simply resistance wire supported in the inner side of a grooved ceramic cylinder. Five heat-reflecting shields surround the heating unit; the inner two are of molybdenum, the outer three of stainless steel.

The carriers, 2 in. in diameter and about 4 in. long, are of alloy steel and fit closely inside the tube. They contain a number of ½-in. holes to permit escape of gas. The outside bearing surfaces of the pistons are flame coated with tungsten carbide to prevent the bare metal surfaces from

Specimen carriers with sample ceramic assembly to be evacuated and sealed. Holes in carriers permit air to be withdrawn inside furnace. Outside bearing surfaces are flame coated with tungsten carbide to prevent carrier from seizing inside furnace tube. (Photo courtesy Sanders Associates, Inc.)

brazing together in the intense heat of the furnace section. This coating is extremely hard; after the machine had been used continuously for 6 months, the coated surfaces showed negligible signs of wear.

Several vacuum pumps are employed to reduce the air pressure near the ends of the tube and to maintain a high degree of vacuum in the central heating section. Relatively little air leaks into the system past the carriers and pistons; the air removed from the central section is mostly that desorbed from the surfaces of the parts entering the system.

A similar machine could well be devised for continuously processing devices other than ceramic radio tubes. The coating of lenses or resistors by vapor plating, and the production of vacuum condensers and switches are possible applications. Where the processed article must come out of the vacuum near room temperature, the lower end of the furnace could be lengthened and water cooled.

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[1] Patent No. 2,894,795, Automatic evacuation system for vacuum tubes, *awarded to C. P. Marsden (14 July 59)*.

[2] Ceramic wafer tubes for modular units, *by C. P. Marsden, Electronics*, **32**, *No. 39 (Sept. 25, 1959)*.

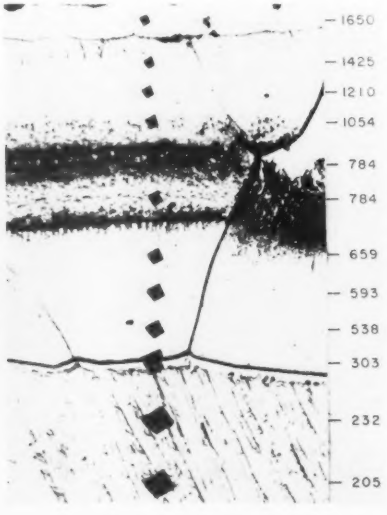
[3] Project Tinkertoy, *NBS Tech. News Bul.* **37**, *11 (Nov. 1953)*.

Nitriding Phenomena in Titanium and a Titanium Alloy

NITRIDING gives a desirable high hardness to the surface of commercially pure titanium but has an adverse effect on the Ti–6A1–4V alloy, according to a National Bureau of Standards study for the Navy Bureau of Weapons.[1] These findings were made by J. R. Cuthill and W. D. Hayes, assisted by R. E. Seebold of the Naval Research Laboratory. As a result of the study, fuel control valves for the jet engines of carrier-based aircraft have been experimentally produced from unalloyed titanium and nitrided. These nitrided titanium parts have displayed good performance characteristics in this application.

Proposed increases in temperature and pressure to improve aircraft engine performance will place increased demands on the durability of metals that are to be used for certain engine components. Such materials must resist galling and wear between surfaces in sliding contact, must have good resistance to impact and to salt water corrosion, be light in weight, and exhibit good machinability. Because the nitriding process often increases the surface hardness of metals, the current study was undertaken. Titanium inherently has excellent salt water corrosion resistance, and also a strong affinity for nitrogen, so it was a logical choice for a starting material. The alloy containing 6-percent aluminum and 4-percent vanadium had recently come into widespread use; also, previous investigators had reported vanadium to be the only alloying element other than boron that increased the diffusion rate of nitrogen through titanium.[2] This alloy was therefore of particular interest.

Over 300 specimens, 9/16 by 2½ in., cut from 0.050 in. thick sheets, were used in the experiments. They were nitrided in purified nitrogen at 1,800° F for 4, 16, 24, 48, 96, or 168 hr, to obtain data on the relation between case thickness and duration of the treatment. A nickel-base



Left: **W. D. Hayes adjusts a microhardness indenter attachment and a projection microscope used to measure the hardness of nitrided specimens.** ***Right:*** **Microstructure and Vickers microhardness indentation (50-g load), with corresponding Vickers hardness numbers, across the case and core of a nitrided titanium specimen. Hardness ranges from Rockwell C77 at the surface to Rockwell C12 in the matrix.**

alloy tube with water-cooled ends was employed as a nitriding chamber. Each specimen, individually drawn into the hot zone by magnetic attraction acting on an attached iron bob, was held at the nitriding temperature for its prescribed time, and then drawn into the cool zone by the same process.

After the nitrided specimens had cooled to room temperature, they were analyzed metallographically. The analysis showed that the unalloyed metal forms a uniformly thick, hard case with a sharp line of demarcation between case and core. The nitride surface layer that forms on the Ti-6A1–4V alloy is thinner than that which forms on the unalloyed titanium, and, in addition, elongated nitride grains form in the alloy and penetrate as far as the center of the core at a 45° angle with the surface. The impact strength of titanium, as determined by transverse impact tests on unnotched specimens, was found not to be impaired as a result of the nitriding. However, after being subjected to the same treatment, the alloy exhibits a serious reduction in its impact resistance. The elongated nitrided grains in the alloy apparently act as stress raisers to reduce impact strength.

Subsequent examination of the alloy with an electron-probe microanalyzer indicated that the vanadium content in the elongated grains was only one-half of that in the surrounding matrix. Also, traverses across the boundaries of the elongated nitride grains indicated no vanadium composition gradient in the matrix in the vicinity of the boundary, but rather, an abrupt change in vanadium from the level in the nitride grain to the level in the matrix. Thermodynamic data obtained from the experiments showed that the aluminum content plays a prominent role in the formation of the grains, and confirmed the electron probe results in regard to vanadium.

The uniformly thick, nitrided case on the unalloyed titanium was found to consist of a surface film 0.0005 in. thick, covering a principal layer of 0.004 in., on specimens treated for 48 hr. The total case thickness increased with increase in nitriding time, following a parabolic law, and reached a thickness in excess of 0.008 in. in 168 hr. This behavior is contrary to that previously observed by other investigators, who found that titanium, nitrided in ammonia, attains a maximum case of approximately 0.004 in., and that further treatment reduces case thickness.[3]

[1] *For further technical details, see* Nitriding phenomena in titanium and the 6A1–4V titanium alloy, *by J. R. Cuthill, W. D. Hayes, and R. E. Scribold, J. Research NBS* **64A**, *119 (1960).*

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